

Final Report on NASA Grant NAG5-4778
Precipitation-Lightning Relationships on a Global Basis
and
A Study of Tropical Continental Convection in TRMM Brazil

Earle R. Williams, PI
Parsons Laboratory
Massachusetts Institute of Technology
Cambridge, MA 02139

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Introduction

This report is concerned with a summary of work completed under NASA Grant NAG5-4778 entitled: "Precipitation-Lightning Relationships on a Global Basis", with a supplement entitled: "A Study of Tropical Continental Convection in TRMM/Brazil". Several areas of endeavor are summarized, some of them concerned directly with the observations from the TRMM satellite, and others focussing on ground based measurements in the NASA TRMM LBA field program in Brazil.

Seasonal March and Modulation of Tropical Rainfall and Electrification

Prior to the launch of the TRMM satellite in 1997, work was undertaken to understand the seasonal march of (climatological) rainfall across tropical continental regions (Lin, 1998). A substantial semiannual signal had been identified in the thunder day data (WMO, 1956) and also appeared in some measures of the global electrical circuit (Williams, 1994). Physically, this signal was attributed to the modulation of tropical insolation as the sun crossed the equatorial region twice each year. Lin (1998) showed that the semiannual signal in both wet bulb potential temperature and rainfall was dominant in the African continent. Curiously, a clear semiannual signal was evident in only a few stations in tropical South America. Based on our subsequent field experience in the Amazon basin (see below), the documented lesser response of South America to semiannual forcing is attributed to a more ocean-like character of the Amazon basin in comparison with the Congo basin.

Quantitative Comparisons of Lightning and Rainfall

The simultaneous availability of quantitative rainfall measurements (with the PR (Precipitation Radar)) and lightning measurements (with the LIS (Lightning Imaging Sensor) in November, 1997, led to comparisons over the global tropics (Labrada, 1999; Rothkin et. al., 2000) for the single month of January, 1998. The analysis centered on PR "squares"—areas of radar surveillance with along-orbit dimensions matched with the radar swath width (215 km). Radar reflectivity was converted to a mass flux ($\text{kg}/\text{m}^2/\text{sec}$) and then integrated over this entire area to arrive at a kg/sec values for each PR square. This procedure was carried out for radar observations both near the surface and at higher altitudes in the mixed phase region of convection. The flash rate observations over the same area (a subset of the nominal 550 km x 550 km footprint of the LIS) were then tallied to enable computations of the rainfall yield per lightning flash.

Consistent with a large body of other evidence that the ice phase is a critical element of the process that generates lightning in moist convection, the precipitation mass flux at the 7 km altitude level (for example) is well correlated with the lightning flash rate. This result is favorable to the use of lightning as an indirect measure of rainfall.

Other findings are less favorable toward this goal. The rainfall totals at the surface are poorly correlated with the lightning flash yield. The least favorable result is that only 5% of PR squares exhibiting rainfall are also producing lightning on a global basis (Labrada, 1999). The physical implication is that weak vertical development is capable of initiating

and sustaining rainfall but is not sufficiently developed also in the ice phase to produce lightning. The latter situation is particularly pronounced over the world's oceans, where lightning activity is reduced by an order of magnitude relative to land.

The Land-Ocean Lightning Contrast

A further assessment of reasons for the dramatic land-ocean lightning contrast was attempted with TRMM observations by producing global maps of all locations for which the radar reflectivity at 7 km (a central altitude in the all-important mixed phase region) exceeded 40 dBZ (Lin, 1998; Labrada, 1999). Almost all such locations are found over continents. This result is consistent with systematically larger updraft in continental convection. The physical origin of this updraft contrast remains unresolved but became another reason for the work in Brazil (see below).

Response of Global Lightning to Global Change

The availability of lightning observations from both NASA's Optical Transient Detector (the prototype for the LIS) and the TRMM LIS enabled further studies of the response of global lightning activity to global change (Williams et. al., 2001). Two time scales were selected for which the forcing of moist convection is well understood: the diurnal and the annual time scale. The same question was asked of the observations in both cases: Is the change in global lightning activity dominated by changes in the number of thunderstorms or by the changes in the flash rate per thunderstorm? Detailed analysis of both OTD and LIS data sets indicated that changes in the number of storms are dominant in controlling the variation in total flash rate. If this result is applicable on still longer time scales (i.e., the interannual and the decadal time scales), then it would support the idea of convective adjustment: a warming of surface air is associated with a warming of the air aloft, with little change in cloud buoyancy and CAPE (Convective Available Potential Energy). The finding also suggests that small increments of CAPE can increase the probability that a convective cloud transitions to thunderstorm status.

TRMM-LBA Field Experiment in Brazil: Tests of the Aerosol Hypothesis for Cloud Electrification

During the TRMM LBA field program in Rondonia, Brazil, Earle Williams served as PI with the NASA TOGA radar near Ouro Preto. This tropical field experiment in a region with highly variable concentrations of cloud condensation nuclei (CCN) provided an excellent opportunity for tests of the aerosol hypothesis for cloud electrification (Williams et. al., 2001). A special CCN count was acquired and operated continuously during this program. The preliminary results from the wet season experiment (January-March, 1999) provided further motivation for a continuation in the so-called premonsoon period in October-December, 1999.

The aerosol hypothesis provides an alternative explanation for the land-ocean contrast in lightning activity and is based on the established land-ocean differences in CCN concentrations. In more polluted continental conditions, cloud droplet radii are expected to remain small, thereby suppressing the coalescence process. This suppression of 'warm' rain over continents enables more liquid water to access the mixed phase region where it can participate in the ice-phase process of charge separation and lightning

production. Additional cloud buoyancy and vertical velocity can also be realized by virtue of the latent heat of freezing.

Four distinct meteorological regimes were examined in Brazil to assess the roles of aerosol and instability on microphysics and cloud electrification: the easterly ('break period') and westerly ('monsoon') regimes in the regular wet season, and the polluted (October) and clean (November) months of the premonsoon. An important normalized parameter for characterizing electrification was the lightning stroke yield per unit mass of rainfall, determined by combining rainfall observations from the TOGA radar and lightning observations from the Brazil Lightning Detection Network. Numerous comparisons have now been carried out and are described in Williams et. al. (2001), but the most telling result is the finding that the stroke yield in highly polluted October was indistinguishable from that in clean November. (The stroke yield in the wet season was notably less than during the premonsoon overall.) This finding casts doubt on a primary role of the aerosol in cloud electrification, and underscores the importance of rather subtle differences in instability (CAPE) in explaining variations in lightning activity.

Student Involvement and Publications

Two students, Sunnia Lin and Carlos Labrada, were fully supported for Master's theses on this grant. Both Labrada and Nadia Madden, an MIT undergraduate student, participated extensively in the radar field program in Brazil in 1999.

Two Master's theses and two journal publications were produced as a result of the NASA support for this study. (The publications are marked in the reference list below.) In addition, preliminary results from this study were reported at two AGU meetings, one AMS meeting, and two LBA meetings in Brazil (one in Sao Paulo and one in Belem).

References

(Starred (*) references are reports/publications resulting from NASA TRMM support)

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